# DEVELOPING AN OCEAN COLOUR SERVICE SUPPORTING GLOBAL CARBON-CYCLE RESEARCH AND OPERATIONAL OCEANOGRAPHY

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**Abstract**

Ocean colour is an "essential climate variable" needed to support carbon cycle monitoring and is globally monitored using satellite observations. In order to cover the long time span necessary for climate monitoring purposes, the required ocean colour data set can only be built by merging together observations made with different satellite systems. To ensure that different periods of the time series can be compared, merging data from differently engineered satellite systems requires thorough calibration and validation covering the entire spatial and temporal extent of the data set.

The GlobColour project has been initiated and funded by the ESA Data User Element Programme to develop a satellite based ocean colour data service to support global carbon-cycle research and operational oceanography. It aims to satisfy the scientific requirement for a long (10+ year) time-series of consistently calibrated global ocean colour information with the best possible spatial coverage. The service is distributing global data sets of chlorophyll-a concentration, normalised water-leaving radiances, diffuse attenuation coefficient, coloured dissolved and detrital organic materials, total suspended matter or particulate backscattering coefficient, turbidity index, cloud fraction and quality indicators. In the future this will feed into the Marine Core Services and utilise Sentinel-3.

## INTRODUCTION

As part of the Earth Observation Envelope Programme, the European Space Agency (ESA) Data User Element (DUE) builds the user community for earth observation data by running projects to develop and demonstrate user driven applications. In so doing, the programme helps to transfer research techniques into viable applications, and puts earth observation to work at the service of Europe's citizens. Several projects have pioneered applications which are being developed into operational services by the European Commission under the Global Monitoring for Environment and Security (GMES) initiative. The DUE also supports scientific programmes and international environmental conventions, such as the United Nations conventions on climate change, desertification, and biodiversity, by providing large scale satellite derived information for global change research and monitoring.

In 2005, the International Ocean Colour Coordinating Group (IOCCG) convened a working group to examine the state of the art in ocean colour data merging, which showed that the research techniques had matured sufficiently for creating long multi-sensor datasets (IOCCG, 2007). As a result, ESA initiated the DUE GlobColour project (http://www.globcolour.info/) and NASA started the Ocean Color Time-Series Project (http://reason.gsfc.nasa.gov/) that builds on their earlier Sensor Intercomparison and Merger for Biological and Interdisciplinary Oceanic Studies (SIMBIOS) programme.

In setting up the GlobColour project, three user organisations were invited to help. Their roles are to specify the detailed user requirements, act as a channel to the broader end user community, and to provide feedback and assessment of the results. The International Ocean Carbon Coordination Project (IOCCP) based at UNESCO in Paris provides direct access to the carbon cycle modelling

community's requirements and to the modellers themselves who will use the final products. The UK Met Office's National Centre for Ocean Forecasting (NCOF) in Exeter, UK, provides an understanding of the requirements of operational users, and the IOCCG brought their understanding of the global user needs and valuable advice on best practice within the ocean colour science community.

The three year project kicked-off in November 2005 under the leadership of ACRI-ST (France). The objective is to produce the best possible global daily ocean colour data set by merging together data from the three most capable sensors: SeaWiFS on GeoEye's Orbview-2 mission, MODIS on NASA's Aqua mission and MERIS on ESA's ENVISAT mission. Parasol was also considered initially, but the products were not available for release at the decision point for inclusion and so may be added at a later stage.

The results of this first year of work were presented at a user consultation workshop organised by the Laboratoire d'Océanographie de Villefranche in France, in December 2006. This was also an opportunity for the wider global user community to hear about the results and to influence the direction of the project; it provided the final stamp of approval on the merging methodology before large scale processing began in 2007. By the end of the project this will include a consistently calibrated time series covering nearly 12 years, from 1997 to 2008.

## PROCESSING AND PRODUCTS

The first year of work, 2006, was devoted to the development and prototyping of the techniques and overall processing system. The main modules of the system (see Figure 1) include: data acquisition; pre-processing; spatial binning; temporal binning; merging; quality control (QC). QC is provided through the Diagnostic Data Sets (DDS), which are extracted sub-areas covering locations of in-situ data collection or interesting oceanographic phenomena.

Error statistics and inter-sensor biases were quantified by comparison with in-situ measurements from moored optical buoys and ship based campaigns. Figure 2 shows the sensor characterisation results for the Chlorophyll-a (Chl1) product, derived using the OC4 algorithm (O'Reilly *et al.* 1998), but the same process was also undertaken for the normalised water leaving radiances and diffuse attenuation coefficient. The worldwide validity of these statistics was then checked by intercomparing the satellite data globally. See the end of first year Product Validation and Assessment Report (PVAR) http://www.globcolour.info/CDR_Docs/GlobCOLOUR_PVAR_v1.2.pdf for further details.

This intercomparison exercise provided a deep understanding of the different input data streams, and led to the prototyping of three different merging methods: simple averaging, error-weighted averaging and an advanced retrieval based on fitting an in-water bio-optical model to the merged set of observed normalised water-leaving radiances (nLw's). This third technique is also being utilised by the NASA Ocean Color Time-Series Project, and is termed GSM because it originates from the Garver *et al.* (1997) bio-optical model (Maritorena & Siegel, 2005). Error statistics from the initial sensor characterisation are also used as an input to both the weighted averaging and GSM merging methods, and propagate through the merging process to provide error estimates on the output merged products. These error estimates are a key component of GlobColour as they are invaluable to the users; particularly the modellers who need them in order to assimilate the ocean colour data into their ocean simulations.

Validation and intercomparison of the four month prototype dataset (the preliminary product set, PPS), and consideration of these results in terms of how best to meet the user's requirements provided the basis for the final merging methodology. The decision was to use different techniques for different products:-

Normalised water-leaving radiances:

- Statistics are slightly better when using the weighted average than the simple average.
- Use of the weighted average for the nLw's.

Chlorophyll-a:

- GSM provides the best fit to in-situ chlorophyll-a.
- It has the advantage of providing other products (Bbp and CDM).
- Pixel-by-pixel error bars can be provided in the future.

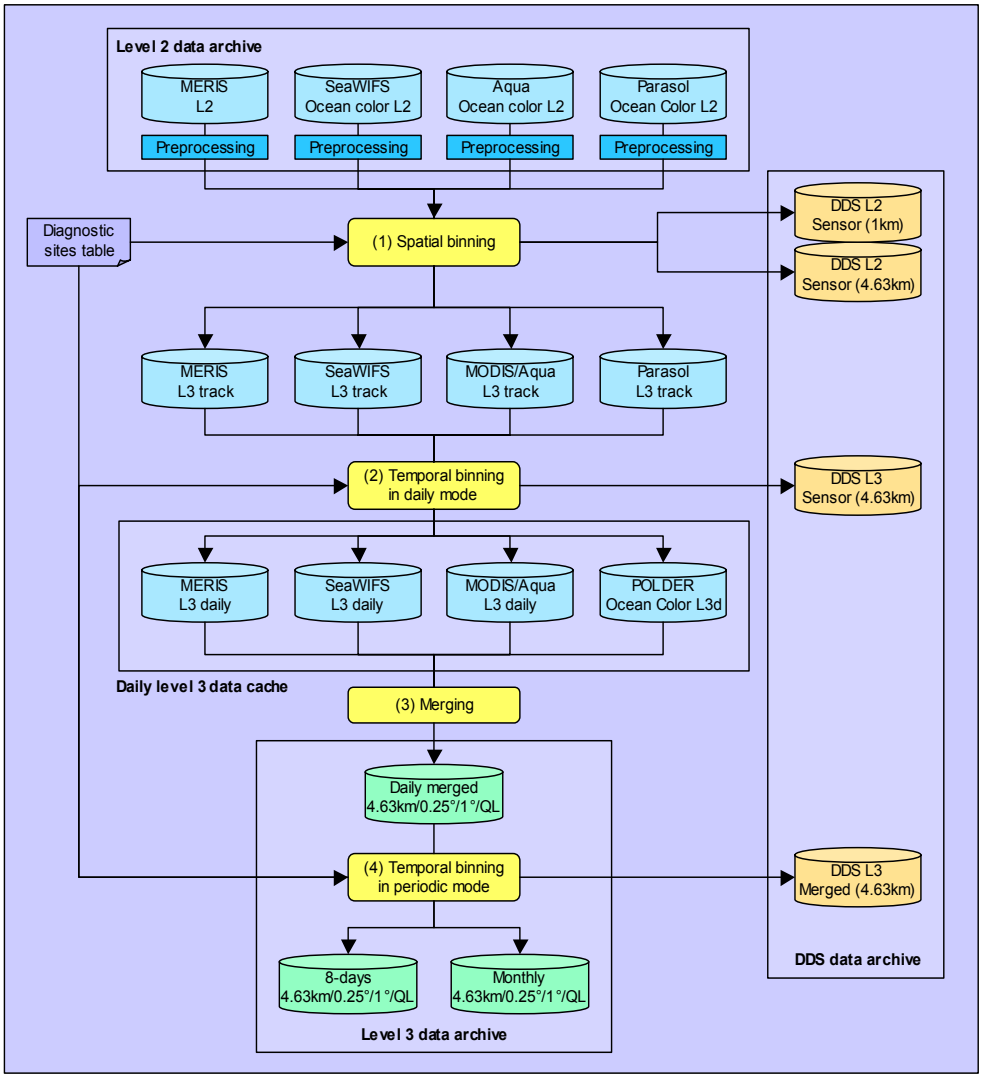


***Figure 1:*** **Schematic of the GlobColour processor.**

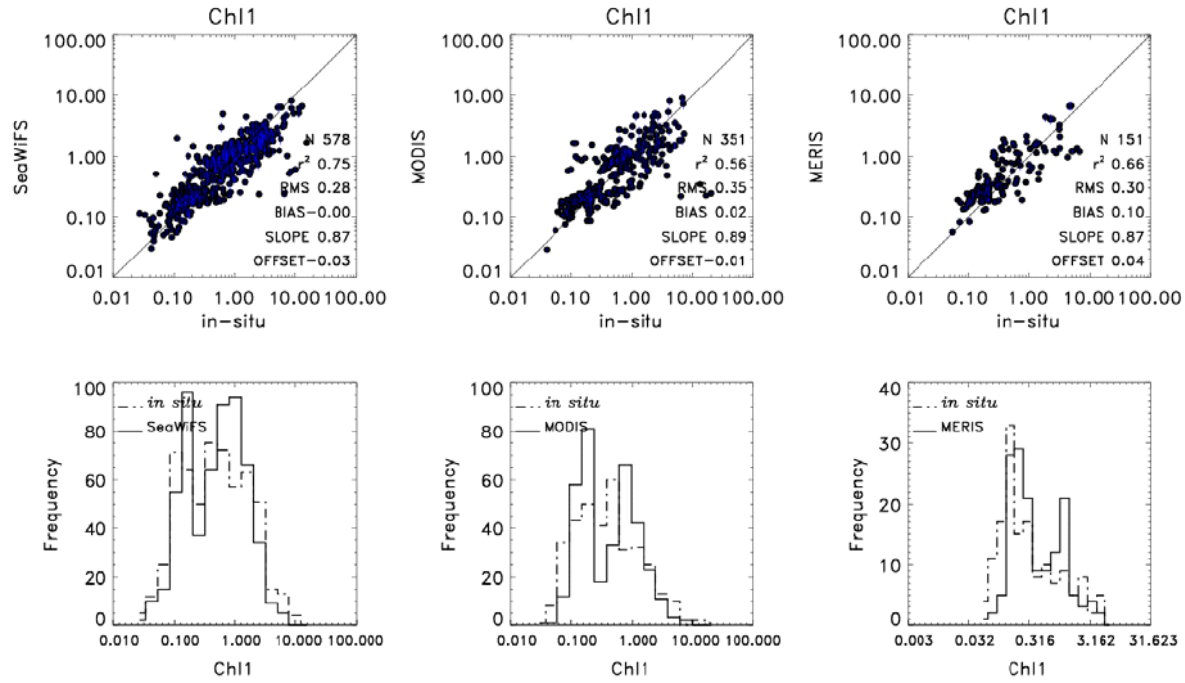


***Figure 2:*** **Example results for Chlorophyll-a from the sensor intercomparison.**

Figure 3 shows an example of the GSM merged Chl1 product. The full list of products is as given below (MODIS-only and MERIS-only):

- Chlorophyll concentration (Chl1)
- Diffuse attenuation coefficient at 490nm (Kd490)
- Total Suspended Matter
- CDM absorption (aCDM443)
- Particle backscattering coefficient (bbp443)
- Aerosol Optical Thickness (T865)
- Exact normalised water-leaving radiance at 412, 443, 490, 510, 531, 555 and 620 nm
- Water-leaving radiance at 670, 681 and 709 nm
- Data quality flags
- Cloud fraction
- Excess of radiance at ~ 555 nm, turbidity index (EL555)
- Error estimates per pixel for each layer

See the Product User Guide (PUG) http://www.globcolour.info/CDR_Docs/GlobCOLOUR_PUG.pdf for further details.

## PROCESSING AND PRODUCTS

In total more than 25 Tb of input (level 2) data have been ingested and 14 Tb of intermediate and output products created, with 4 Tb of data distributed to the user community. The Full Product Set (FPS) covers global daily merged ocean colour products in the time period 1997-2006 and is now available for validation at http://www.globcolour.info/data_access_full_prod_set.html .

An intensive phase of validation is being undertaken to assess the quality of the data set. In addition, inter-comparisons between the different merged datasets will help in further refining the techniques used. Both the final products and the quality assessment will be presented at a second user consultation in Oslo (20-22 November 2007). The data will then be made freely available for use by the worldwide science community.

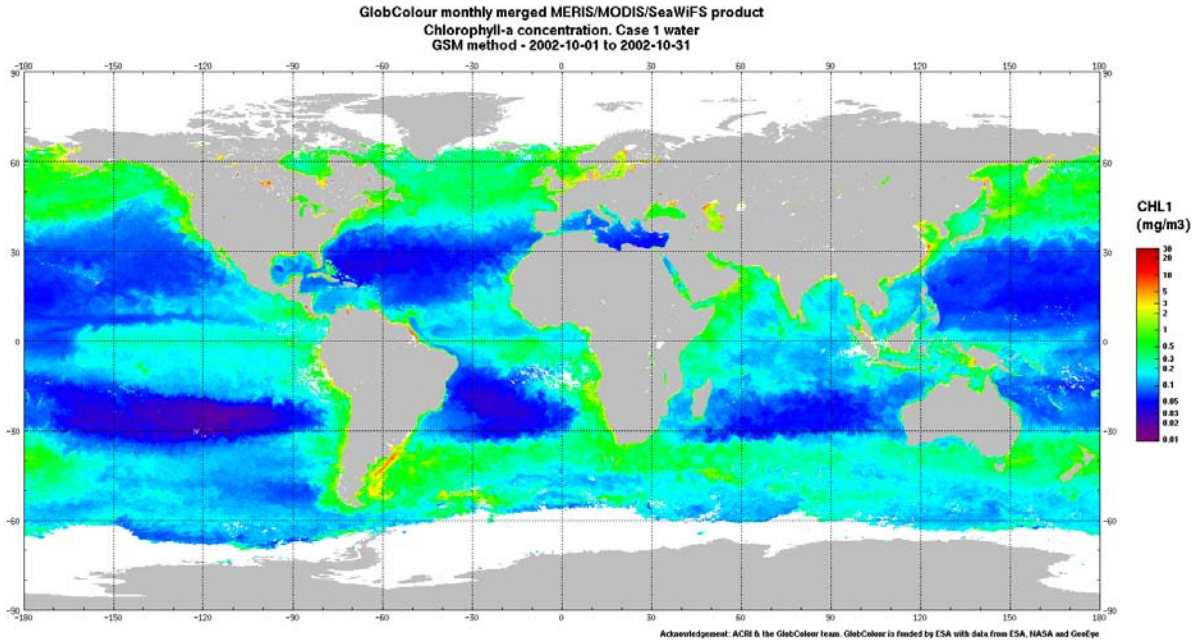


***Figure 3:*** **Example of the GSM Chlorophyll-a merged product.**

## FUTURE

In 2008, the project will continue merging ocean colour data, but will re-use what it has developed to support operational oceanography. This will tie into the European Community funded Marine Core Service that will start to provide, in 2008, a suite of operational services to support Europe's decision makers. GlobColour's merged ocean colour dataset will be within the future Ocean Colour Thematic Assembly Centre (OC TAC) whose main objective is to bridge the gap between space agencies providing ocean colour data and GMES marine applications. The OC TAC will deliver core ocean colour products, annotated with quality control flags and reliable error estimates at pixel level at global to regional European scales, consolidating European efforts and maximising their impact. The aim is to integrate the best components of existing pre-operational systems developed in the last few years by member states, ESA and European projects like GlobColour, MarCoast and Mersea into a common European system, filling gaps and creating a common external interface.

## ACKNOWLEDGEMENT

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